

## THE Eocene of Patagonia

By George Gaylord Simpson

In previous papers (Simpson 1933, 1935a, 1935b) I have discussed the general stratigraphy and nomenclature of the early to middle Tertiary terrestrial formations of Patagonia and the local stratigraphy of the interesting and crucial Gaiman region, on the Chubut River. Since those publications, a semi-official stratigraphic no-

menclator has been issued by Argentine government geologists and several important papers on the Gaiman region have appeared. These authors invite comment, and a review of the present status of the usages and problems involved may be of considerable interest to northern stratigraphers and paleontologists.

## STRATIGRAPHIC TAXONOMY

Fossa-Mancini, Feruglio, and Jussen de Campana (1938) have recently issued a classification and nomenclature of the Patagonian sedimentary rocks. This is based on the collaboration of various local workers and is intended to help standardize usage and to serve as a basis for work in the Y. P. F. (Yacimientos Petroliferos Fiscales, the government organization for the discovery and development of oil fields). It is thus highly authoritative and semi-official in character. Only the parts concerning the mammal-bearing formations between the marine Salamanca (latest Cretaceous or early Paleocene) and the marine Patagonian (late Oligocene or early Miocene) will be discussed here. The early history of the classification has been traced in detail by Frenguelli (1930) and more briefly by me (1933) and need not now be reviewed. The accompanying diagram shows the development of this subject in five pertinent papers appearing since Frenguelli's review of 1930.

Although none of the names used by him were strictly new, the modern nomenclature of these strata essentially dates from Frenguelli's paper of 1930 which is, as I have elsewhere acknowledged, an outstanding work to which all Patagonian stratigraphers are greatly indebted. I modified

it, mainly on the basis of new studies and discoveries, in these ways:

(1) By recognizing (in 1935) that the uppermost terrestrial beds near Trelew and Gaiman are decidedly different from those south of Colhué-Huapi in facies and perhaps later in age. Rejected by Frenguelli, not considered by the Y. P. F., strengthened and made more definite by Bordas.

(2) By recognizing that Ameghino's *Astraponotus*-beds are a separate, definable, and nameable unit, using for it Kraglievich's name *Mustersense* (or *Musters*). Rejected by Frenguelli, accepted by the Y. P. F. and by Bordas.

(3) By rejecting correlation of the beds below the Casamayor with the Sehuenense and proposing the new name Río Chico. Accepted by Frenguelli and Bordas. Definition and correlation accepted by Y. P. F. but name Pehuenche used.

The Y. P. F. report made the following additional modifications:

(4) Applying a group name "Tobas de Sarmiento" to series from Casamayor to Colhué-Huapi, inclusive.

(5) Inserting the "Tobas de Koluel-Kaike" between the Río Chico (their "Pehuenche") and the Casamayor.

Each of these disputed modifications may be briefly discussed.

(1) In 1933 I had not studied the beds at Trelew and Gaiman and accepted the then universal opinion that they were the same as the so-called *Colpodon*-beds south of Lake Colhué-Huapi. I then preferred

for this supposed unit the prior name Colhuehuapiense of Carlos Ameghino as revived by Frenguelli. In 1935 when I had studied the beds at Trelew and Gaiman, I found that they differ notably from the typical Colhuehuapiense and provisionally revived for them Kraglievich's local name Trelewense, noting that this was a partial redefinition, or a more exact definition, since Kraglievich believed his Trelewense to be the same formation as the *Colpodon*-beds of Colhué-Huapí. Frenguelli rejected my proposal on the grounds that Colhuehuapiense and Trelewense are strict synonyms and that the two deposits in question do not differ enough to warrant

ably in age, facies, or both. These deposits are widely discontinuous, are different in facies, and may be different in age. In 1935, on the basis of preliminary study of a small collection of mammals, I suggested that the Trelew beds might be later than the Colhué-Huapí. In 1939, after more detailed study of a larger collection, Bordas concluded that they are definitely later. It does not follow that the two names are of equal scope or that they are not both parts of one unit of higher rank, but these facts do warrant the use of different stratigraphic names for clarity and exactness.

Part of the difficulty here is that Fren-

Frenguelli, 1930	Simpson, 1933	Simpson, 1935	Frenguelli, 1935	Y. P. F., 1938		Bordas, 1939
Colhuehua- piense	Colhuehua- piense = Colhué-Huapí	Trelewense = Trelew ?	Colhuehua- piense	Sarmiento	Colhué- Huapí	Trelewense
		Colhué-Huapí			Colhuehua- piense	
Deseadense	Deseadense = Deseado	Deseado	Deseadense		Deseado	Deseadense
	Mustersense = Musters	Musters			Musters	Mustersense
Casamayo- rense	Casamayorense = Casamayor	Casamayor	Casamayo- rense		Casamayor	Casamayo- rense
Sehuenense	Ríoichiense = Río Chico	Río Chico	Ríochi- quense	Koluel-Kaike		Ríochi- quense
				Pehuenche		

the introduction of a new name for one of them. But by absolute tautonymy and the explicit intentions of their authors, the type locality of the Colhuehuapiense is the barranca south of Lake Colhué-Huapí and that of the Trelewense is the region of Trelew (and its neighboring village, Gaiman). The synonymy depends on the correlation of these widely separate deposits and if these are not the same thing the terms are not synonymous even if their authors thought that they were. The difference between the two type deposits is not great but it is real. General usage throughout the world sanctions and demands the use of separate local names for stratigraphic units if they are discontinuous geographically and if they differ appreci-

guelli, like many other stratigraphers, is attempting to set up a standard column for all of Patagonia or of the Argentine and to maintain that terrestrial deposits of (about) the same age necessarily represent the same formation (or horizon or stratigraphic stage). As discussed on a later page, I believe such an arrangement to be impractical because it confuses age units with rock units, two quite different things.<sup>1</sup>

(2) I am engaged in a revision of the Musters fauna, to appear later. It will save confusion to state now that Ameghino was correct in thinking that this

<sup>1</sup> Incidentally the discussion would be on a somewhat different basis if Trelew had been a new name when I used it, but it was not.

fauna is distinctive either from Deseado or Casamayor and not merely a phase of one or the other. On the whole it is closer to Casamayor than to Deseado, but as far as the typical faunas are concerned it is separated by marked hiatuses from both. The stratigraphic development of the Musters formation is limited in the few localities where it has been studied, but there are indications that it has a large development in regions not yet sufficiently explored. Even now it can be recognized as a definable rock (as well as faunal) unit, readily separable from the Deseado where both occur.

(3) The essential character of the Río Chico formation or series and its Tertiary, not Cretaceous, age is now generally accepted. Such disagreement as exists is mostly nominal, whether to call these beds Río Chico or Pehuenche. The history of the name "Pehuenche" has been discussed by Frenguelli, me, and the Y. P. F. geologists and need not be repeated beyond stating these undisputed facts:

The type Pehuenche of Doering, 1882, is certainly of Cretaceous age and is exposed near Roca in northwestern Patagonia. It is probably synchronous with, but as a rock unit is quite distinct from, beds in central Patagonia.

Ameghino at various times (e.g., his great work of 1906) used the name Pehuenche for certain beds in central Patagonia immediately below the Salamanca. This was not a proposal of a new name or a new definition. It was a correlation with the type Pehuenche. The beds so correlated by Ameghino are, like the type Pehuenche, indubitably of late Cretaceous age; they probably are later than the type Pehuenche, although this is uncertain.

For some forty-five years the name Pehuenche was in common use and was used only for beds supposed to be (and in almost every case correctly) Cretaceous in age and on the basis of correlation (usually not exactly correct) with the type Pehuenche. It is still used by various workers in this sense.

But a decade or so ago some of the Y. P. F. geologists began applying the name to beds above the Salamanca, mostly

in the mistaken belief that they were Ameghino's Pehuenche (they were really his "Notostylopense basal") and in the equally mistaken belief that they were of Upper Cretaceous age.

Whatever can be said of Ameghino's Pehuenche, the Y. P. F. Pehuenche certainly has nothing to do, in age, facies, or fauna, either with Ameghino's Pehuenche or with the type Pehuenche. The Y. P. F. geologists defend their usage only on the basis of its general adoption, but it is, as they admit, absolutely incorrect and extremely confusing and the "general adoption" is only in recent years and only in their own work, most other students rejecting their error. The general adoption of an error (even when it is general) is not a very sound argument for its perpetuation after its falsity has been exposed. I can only express entire agreement with the Y. P. F. geologists when they say that "it would be wisest to abide by the name Río Chico" and that this "offers the advantage of not lending itself to confusion," with surprise that they themselves see fit to reject what they designate as the wise and proper course in the matter.<sup>1</sup>

(4) Field workers doing gross reconnaissance have generally given one name to the whole tuff-bentonite series between the Río Chico and the Patagonia formations. It is true that it is difficult to trace or map formational units in this series on lithology alone. The lithology is remarkably varied in detail but similar in the mass. Units well recognizable in a given section usually cannot be traced far laterally. From the practical point of view of rapid and crude mapping, and especially for the oil geologist who has no immediate interest in these nonpetroliferous deposits, there is, then, some advantage in the use of such a broad name, and that now proposed by the Y. P. F., "Sarmiento," is acceptable and greatly preferable to those previously used, some of which were ridiculous (e.g., Windhausen's "tobas mamíferas").

<sup>1</sup> Since this paper was written, the Y. P. F. has published an excellent geological map of Patagonia by Dr. Feruglio. On this the beds in question are called Riochiquense "which in Chubut is customarily referred to the Pehuenche."



On the other hand, for the progress of careful work and detailed stratigraphy, such a term may do as much harm as good. From a temporal point of view, it is of unwieldy size, covering all the strata deposited during about two epochs, and perhaps part of a third. At every locality where I have seen these rocks, it is always possible by careful work to define the age of a particular exposure far more exactly than this. Although often sparsely fossiliferous, these rocks do everywhere contain some fossils. Moreover by correlating the well-defined but variable lithologic variations with fossil discoveries, it is entirely possible in any given region to divide this series into valid and recognizable stratigraphic formations. Since, as far as has been shown, this can always be done when the effort is made, the use of a single name for the whole series is not a real necessity and may tend merely to retard necessary progress in the study of these very important strata and their faunas.

(5) The Y. P. F. name "Koluel-Kaike" applies to a purely lithologic unit (if it is a unit), Ameghino's "argiles fissilaires,"

which usually occurs between the Rio Chico and the Casamayor. Since more or less similar rocks do, less commonly, occur at other levels, this is not a proper stratigraphic term unless it is defined not only by lithology but also by the specification of its being confined to the more or less continuous sheet of such rocks below un-silicified tuffs with Casamayor fossils in southern Chubut and northern Santa Cruz territories. Even this sheet, although a proper stratigraphic (not temporal or faunal) unit is probably of somewhat different ages in different places. It is probably usually contemporaneous with the oldest parts of the Casamayor. No fossils have been found in it. It probably has no proper place in a generalized Patagonian stratigraphic column, and certainly does not now belong in a generalized time scale for the region. My present opinion is that it does not represent any time not also represented by fossil-bearing strata of different name and character in Patagonia, although of course this opinion is subject to correction by discovery of new facts.

#### TIME, ROCKS, AND FAUNAS

As in North American geology, the stratigraphic taxonomy of Argentina has been confused by a lack of clarity in distinguishing units and names applicable to rocks, to faunas, and to time. The following summarizes the taxonomic arrangement sponsored jointly by the Association of American State Geologists, the U. S. Geological Survey, the American Association of Petroleum Geologists, and the Geological Society of America (reference under Ashley, etc., 1933).

The names in parentheses are mentioned but not explicitly recommended by the

report in question. That in brackets is not mentioned but has recently come into general use, especially by vertebrate paleontologists.

Eras, periods, and epochs have world-wide names, familiar to all of us, e.g., Paleozoic, Cretaceous, Eocene. Subepochs, ages, and phases, if named, have provincial names that are not world-wide but apply over as large an area as can readily be involved in fairly precise chronologic correlation, e.g., Pontian in the Old World or Lutetian in Europe, names geographic in origin and, as a rule, with the ending -an

Time		Rocks		Faunas
Era	} Theoretical equivalence	(No name)	} No specified equivalence	(No faunal name)
Period		System		
Epoch		Series		
(Subepoch)	} Approximate but not necessarily exact equivalence	Group	} No specified equivalence	} Zone [Local fauna]
(Age, Stage)		Formation		
(Phase)		Member (Stratum)		

in English. These names are commonly, but not by technical necessity, derived from those of included or approximately equivalent rock units.

Systems have the same name as the corresponding periods, and series may have the names of epochs or may have provincial geographic names. Groups, formations, and members have geographic names, used in North America without modification or special termination. A single stratum is not usually named.

Zones are given faunal (or floral) names, from a genus, species, or occasionally subspecies that characterizes each. There is a tendency for vertebrate paleontologists to deprecate their use as unnecessary and essentially undefinable, a feeling that I share, generally speaking. In some cases, however, they are useful, or are considered so by many teachers, stratigraphers, and some paleontologists, so that it is desirable to supply them when conveniently possible. Local faunas are given the names of the localities where they occur, without entering into questions of priority, synonymy, etc., involved in the more formalized use of geographic names for rock and time units, e.g., one may speak of a lower Casamayor local fauna at Colhué-Huapí without meaning or implying any

North American Arrangement	Y. P. F. Arrangement
System } Series }	Used but not explicitly defined
Group	Complejo
Formation	Formación
Member	Sección

The Y. P. F. arrangement uses the world-wide system and series names in Spanish forms, e.g., Terciario, Senoniano, Triásico. For the smaller and more explicitly rock units, they generally use unmodified local geographic names, e.g., Complejo porfirico de Bahía Laura, Tobas de Sarmiento, Estratos de Bustamante, Formación de Roca, Chubut. Occasionally they use the more classic Argentine terms in -iano and -ense, without explicit differentiation of their rank, e.g., Rionegrense, Santacruciano. They do not, as a rule, use the same name for a "complejo" and any one of its included "formaciones" or for a "formación" and any included "sección."

The arrangements of Kraglievich and Frenguelli, the former derived from Ameghino without essential change and the latter a modification of Ameghino's arrangement, are as follows. Their equivalence with the North American arrangement (published later) is not conscious or intended to be exact, as is that of the Y. P. F.

North American Arrangement	Kraglievich 1930	Frenguelli 1930
System	(Not used)	Sistema. -ico
Series		Grupo. -iano
Group	Formación. -ana	(Usually with scope of a series)
Formation	Horizonte. -ense	Horizonte. -ense
Member	(Usually with scope of a formation)	(Usually with scope of a formation)

relationship to the Colhué-Huapí formation or to a Colhuehuapian age.

There is no thought of imposing this arrangement in the United States or anywhere else, but it does provide a reasonably standardized synthesis of widespread usage. As such it is cited in the Y. P. F. report which, for rock terms, specifies equations between its Spanish and the English of the North American report, as follows:

Kraglievich and Frenguelli use provincial geographic names (even for systems, in the case of Frenguelli) with the endings indicated.<sup>1</sup> They commonly use the same name with different endings in different senses, which is clear enough as they use

<sup>1</sup> Ameghino did the same, sometimes with geographic names and sometimes with generic zoologic names, e.g., Paranense from Paraná, a geographic locality, *Notostylopsense* from *Notostylops*, a fossil mammal.

it but confusing to anyone not well acquainted with Argentine geologic literature. For instance, Kraglievich's "Friaseana" includes a much smaller "Friaseense" along with two other "horizontes," and Frenguelli's "Patagónico" includes a much smaller "Patagoniano," just as his "Deseadiano" includes a much smaller "Deseadense."

The use of the word "formación" in Kraglievich's (and Ameghino's) sense will perhaps be abandoned, as it has been by Frenguelli and by the Y. P. F. It has some historical justification but is contrary to the most widespread modern usage. Kraglievich's and Frenguelli's use of "horizonte" was abandoned by the Y. P. F. (as was "horizon" in a similar sense in the North American report) for the cogent reason that "horizonte" in Spanish, like its English cognate word, correctly means a plane and not a unit with thickness.<sup>1</sup>

Neither Ameghino nor Kraglievich made any clear distinction between faunal and rock names; significantly, neither one was a field worker or collector. Fundamentally and as a rule they were really studying and naming faunas, not strata, and without clear definition they extended names erected on this basis to strata, not really thinking in terms of rocks but with the implicit idea that strata must correspond with known faunas. This is shown, among many other things, by the fact that Ameghino commonly named strata for genera and used identical names for strata and for faunas, and that Kraglievich defined all his names not in terms of lithology or bounding horizons but in terms of faunas only, even calling a "formación" a "Ciclo faunístico."

Like most North American geologists, none of the Argentine stratigraphers (as far as I know) has clearly distinguished time and rock units. They speak of time, if at all, either in terms of rocks and faunas or in terms of the world-wide, not provincial, epochs and periods. There is at present in North America a strong drift

<sup>1</sup> Ameghino also used "horizonte" or (in French) "horizon" in this sense, as did many geologists of his period, but preferred "piso" = "étage," a better term but also now usually rejected in this sense because "étage" or "stage" is generally understood to be a time, not a rock, unit.

away from either of these methods and the reasons for this clearer differentiation of time and rock names and units are still more impelling in the Argentine than in the United States. A faunal zone (or a zonal fauna) may run through several formations. One formation may be of different ages in different places. Two formations may be quite distinct and yet have the same age and the same fauna, or the same age and different faunas. Clarity and convenience can only be served in such cases by having time names distinct from rock or faunal names. The use of the world-wide time names in the Argentine is particularly confusing, because they imply at least an approximate world-wide correlation, and as to this there is no consensus at present. For instance, when Kraglievich, Castellanos, Frenguelli, and Scott speak of the Later or Upper Oligocene of the Argentine, they are referring not to the same but to four different times. If they speak of the Chasicó they are at least thinking of the same fauna, and probably but more questionably of the same formation and age. Kraglievich, for instance, might be speaking of any beds or faunas that he correlated with the Chasicó on a purely faunal basis, whether or not they really were to a stratigrapher the same formation as that exposed at Chasicó. This leads back to the difficulty that it is quite impossible to do what most Argentine geologists and paleontologists have attempted but the Y. P. F. has now wisely abandoned: to build up a single standard stratigraphic sequence for the whole Argentine or even for a considerable part of it. At the same time it emphasizes the need for non-stratigraphic time terms to use in provincial correlation.

The following table is a first attempt at a system for the times, rocks, and faunas here under discussion in which these three quite different things are clearly distinguished.

The Sarmiento is here inserted as a provincial series, although not wholeheartedly approved. It is not a "complejo" in the Y. P. F. sense, equal to a "group" in the North American sense, because its actual scope is surely far greater,



probably between that of a series and of a system. In its provincial use it corresponds more nearly with a series than with any other standard unit.

The Río Chico is very tentatively inserted as a series but can equally well, at present, be called a formation. In various

The clear distinction of age and rock names, in contrast with the previous attempts to make one set of names serve both purposes, will make possible the more exact and less ambiguous definition of all the formations in their true sense, as local rock units defined in most cases by lithology

Ages	Rocks			Faunas	
	Series	Formations	Members	Zones	Local Faunas
Colhuehuapian	Sarmiento	Trelew	Not distinguished in any one section	<i>Colpodon</i>	Trelew-Gaiman Colhué-Huapí —and others
		Colhué-Huapí			
Deseadan		Deseado and at least one more, unnamed	Several in each formation, not yet defined	<i>Pyrotherium</i>	Canquel (2 or 3 faunules) Cerro del Humo Colhué-Huapí Cabeza Blanca La Flecha —and several more
Mustersian		Musters and probably one more, unnamed	Not distinguished in any one section	<i>Astraponotus</i>	Cerro del Humo Colhué-Huapí Cañadón Colorado —and perhaps others
Casamayoran		Casamayor, and probably others, not defined	Several, not defined	<i>Notostylops</i>	Colhué-Huapí (at least 2 faunules) Cañadón Vaca Cañadón Hondo Canquel —and many others
		~~~~~ ? ~~~~~ Koluel-Kaike ?	Not distinguished	?	None
Riochican	Río Chico	Probably several, not defined	Probably several, not defined	<i>Ernestokokenia chaishoer</i> <i>Kibenikhorja</i> <i>Carodnia</i>	Palangana Gaiman Cerro Redondo Cañadón Hondo Palangana
Salamancan	?	Salamanca	Banco verde Fragmentosa Glaucóntico Lignitífero	Not defined (marine and brackish)	Many
—?—		Bustamante	Left-pan	<i>Trigonia bustamantina</i> , etc.	Several

places it probably covers most or all of an epoch, which would mean that it had nearly or quite the rank of a series. Constituent formations or members have not yet been clearly distinguished, although I have no doubt that they can and will be if more extensive and intensive work is done.

and fossils together, in some cases by lithology alone. Several of the accepted provincial age units clearly cover more than one local rock unit and further work will now permit the definition of such units without their confusion with age units. It is, of course, assumed that each age unit covers a span of time and can

correspond with rock units of appreciably but not greatly different precise ages. It is also anticipated that the discovery of strata and faunas intermediate between those hitherto described will fill in some of the great hiatuses in the sequence and lead either to redefinition of these age names or to intercalation of others, e.g., between Mustersian and Deseadan.

The chart reveals how little is really known about this sequence and that vir-

tually all the detailed and truly careful work remains to be done. For instance, the differences between two local faunas obtained from one formation have never been revealed in any case, although marked and important differences of this sort exist.<sup>1</sup> The sequence of the local faunas is almost completely unknown, although this is the fundamental basis of the early Tertiary history of the region.

## WORLD-WIDE CORRELATION

There is no more difficult problem in South American geology than the assignment of the various terrestrial formations and provincial ages of the Argentine to their proper world-wide epochs, which can only be correctly done by correlating them with North American and European formations and ages. The data are so diffuse and so many of them, as regards the ages here considered, are unpublished and seem destined to remain so for a long time, that no full discussion or well-rounded summary is possible in this paper. It is, however, useful to point out trends of opinion and the conclusions that have so far been drawn from extensive unpublished studies.

Some indication of the differences of opinion may be gained by reviewing the ages assigned by various students to three formations from which large mammalian faunas are known:

### Casamayor:

- Upper Cretaceous—Ameghino, Ihering, Doering, Roth.
- Paleocene—Gaudry.
- Paleocene and Lower Eocene—Kraglievich.
- Lower Eocene—Windhausen, Rovereto, Simpson.
- Lower and Middle Eocene—Castellanos.
- Upper Eocene—Matthew, Schlosser, Patterson.
- Lower Oligocene—Frenguelli.

### Deseado:

- Upper Cretaceous—Ameghino, Doering.
- Lower Eocene—Rovereto.
- Middle Eocene—Ihering.
- Upper Eocene—Windhausen, Roth, Gaudry, Kraglievich.
- Lower Oligocene—Castellanos.
- Lower to Middle Oligocene—Simpson.
- Middle or Upper Oligocene—Patterson.
- Upper Oligocene—Wilckens, Frenguelli.

### Santa Cruz:

- Upper Eocene—Ameghino, Doering.
- Middle Oligocene—Rovereto.
- Upper Oligocene—Ihering, Roth, Kraglievich.
- Lower Miocene—Windhausen, Castellanos, Simpson.
- Middle Miocene—Scott, Patterson.
- Upper Miocene—Wilckens, Frenguelli, Matthew.

(Numerous other students could be cited, but their opinions on each point would nearly or quite coincide with one included here. The table is intended only to show the general divergence of opinion and does not show the development of opinion by any one student. Most have changed their opinions at various times, but each at some time has expressed the opinion here ascribed to him. Nor is it convenient or necessary for the present purpose to show the doubts and cautions expressed. For instance, I do not by any means consider the Lower Eocene age of the Casamayor as certain, but since I do think it slightly more likely on present evidence than any other equally limited age assignment, I have listed myself as supporting this correlation.)

Disregarding, for the moment, the details of correlation, different students show different general tendencies as to the age of this part of the series as a whole. Thus Ameghino consistently made older correlations than most students and Frenguelli consistently makes younger correlations. On this basis the authors cited, as well as those not cited, can be divided with reasonable clarity into five groups, which are

<sup>1</sup> Some are shown by materials now in my hands and will be discussed in a forthcoming memoir.



as follows in the order of their tendency to make the series as a whole older to younger from 1 to 5:

1. Ameghino, Doering.
2. Ihering, Roth, Rovereto, Kraglievich.
3. Gaudry, Windhausen, Castellanos, Simpson.
4. Scott, Matthew, Patterson.
5. Wilckens, Frenguelli.

These do not represent schools of thought in the proper sense, but for the most part independent conclusions that happen, in each group, to coincide approximately as to age tendency. For instance, although I agree more or less with Gaudry, Windhausen, and Castellanos as to the general age and span of this part of the stratigraphic column, I reached this conclusion by independent study of the data, including much not known to them, and I believe some of their reasons for this assignment and some of their particular formation correlations to be invalid.

It has often been remarked that the Argentines tend to make this part of the series older than do non-Argentines. The tabulation here given shows that such a nationalistic bias does not now really exist. Both Argentines and non-Argentines could be listed in each group, and it happens that the leading exponent of extreme late age assignments, Frenguelli, is an Argentine.

Little approach toward agreement has as yet been indicated in correlation with advancing knowledge and new discoveries. I believe that no modern student could be placed in group 1 with Ameghino, but each of the other four, still very divergent, has competent supporters at the present time. Kraglievich supported the general age assignment of group 2 in 1930 and I believe Rusconi maintains Kraglievich's opinion today. Castellanos belonged in group 3 in 1937 and probably still does, as do I. Scott maintained the position indicated for him above in 1937 and does now as far as I know. Frenguelli's extreme views were explicitly published in 1934 and I am not aware that he has changed them significantly. Moreover each group, except the first, now includes students of considerable authority and well acquainted with

the most essential data. A weak consensus of living students would favor group 3, or a position between this and 4,<sup>1</sup> and this position also has the advantage of being about midway between the extremes. It is in these respects (and these only) slightly more authoritative and probable, but the question is not one that can really be settled by consensus or by compromise.

The following tabulation of correlations of all the provincial stages from Salaman-can to Santacrucian includes representatives of each of the five general groups just discussed as well as the correlations tentatively supported in the present paper. The Eocene-Oligocene boundary is indicated by a double line (one dotted if alternative positions are given) in order to make the general age tendencies more apparent.

The principal lines of evidence on which such correlations can be or have been based are as follows:

**TECTONIC MOVEMENTS.**—Tectonic evidence was once used as partial support for drawing the Cretaceous-Tertiary boundary below the Casamayor, but this has been shown to be erroneous and is now abandoned. The occurrence of folding and erosion between Deseadan and Patagonian is established and tends to emphasize the presence here of a hiatus in the known series, evidently between Deseadan and Colhuehuapian. Since, however, this and other supposed or real tectonic phases have not been correlated with those on any other continent, their usefulness in establishing synchrony is slight or nil.

**THICKNESS OF STRATA.**—This means of estimating the relative durations of the various formations is at present of no value here. No valid idea of relative speeds of deposition has been gained. The series is replete with hiatuses, both intra- and interformational, of unknown duration and value. The maximum thicknesses are not well established and for some formations, notably the Musters, no good thickness determination has yet been published.

**TYPE OF FOSSILIZATION.**—As regards the Santa Cruz fossils, Matthew believed that the sediments in which they occur

<sup>1</sup> In fact the step between these is not large, being smaller, for instance, than that between 2 and 3.

and the climatic conditions were closely analogous to those of some North American fossils, like those from the Bridger and John Day, and that supposedly more recent aspect of the Santa Cruz bones was therefore suggestive supporting evidence of their more recent age. The method is tempting, but it has never really been accorded a proper scientific test. It is extremely doubtful whether even such an authority as Matthew could really judge

most recent students to be entirely inapplicable.

DIVERSITY AND FACIES OF FAUNAS.—Castellanos has suggested but has not followed the use of these vague criteria, suggesting that the fauna of the Casamayor compares in these respects with Oligocene faunas of the rest of the world. Even granting the comparison (which I think doubtful or incorrect), the age correlation does not follow, as Castellanos

	Correlation					
Provincial Ages	Ameghino 1906	Kraglievich 1930	Castellanos 1937	Scott 1937	Frenguelli 1934	This Paper
Santacrucian	Eocene (including Paleocene)	Oligocene	Lower Miocene	Lower to Middle Miocene	Miocene	Early Miocene
Patagonian			Oligocene			Latest Oligo- cene or earliest Miocene
Colhuehuapian						
Deseadan	Upper Cretaceous	Eocene		Oligocene	Oligocene	Oligocene
Mustersian			Eocene or Oligocene	~~~~~ Hiatus ~~~~~		
Casamayoran			Eocene	Eocene		Eocene
Riochican				Paleocene		(Paleocene absent)
Salamancan	= Casa mayoran	Upper Cretaceous	Upper Cretaceous	Upper Cretaceous	Upper Cretaceous	Paleocene

the relative degree of fossilization without controlled analysis and could really determine that fossilization occurred in the same way and at the same rate in areas so disparate. This method seems to me now to have no value for correlation in the present instance.

PERCENTAGE OF EXTINCT FORMS.—This method is sometimes used in Pleistocene mammalian correlation and in Tertiary molluscan correlation, but many students have exposed its pitfalls. Ameghino used it to a slight extent in correlating the present series. Under the conditions here obtaining, the method seems to me and to

agrees, since he calls the Casamayor Lower to Middle Eocene.<sup>1</sup>

GENERAL EVOLUTIONARY STAGE.—Judgment as to degree of evolution undoubtedly colors most opinions on Patagonian correlation. Some validity must be granted this sort of evidence. For instance, almost anyone familiar with fossil mammals in general would grant that the fauna of the Casamayor is Eocene (not necessarily Eocene) on this basis alone but this is not very useful because that fact is now

<sup>1</sup> I.e., the Casamayor in my sense, which is the usual one. Castellanos follows Kraglievich in separating Ameghino's lower "Notostylopense" as a distinct formation, a separation resting on no valid definition.

thoroughly established on more objective evidence. Whether closer and useful correlation is possible on these grounds is dubious. It assumes that the two faunal sequences to be compared, e.g., South American and North American, departed at a given time from the same basis and evolved in analogous ways and at about the same rate, and that comparable evolutionary stages can be selected with some accuracy. These assumptions are here doubtful in the extreme and become quite unwarranted when they must be applied to very unlike animals far from any common origin. In earlier times, up to about Mustersian at latest, there are, however, a few South American mammals that are not so distant from North American forms. These do give suggestive but inconclusive evidence in this field. For instance, if, as I believe, the Casamayoran didolodontids are related to the North American phenacodonts, they suggest a degree of evolution comparable very approximately to early Eocene in North America.

**MAMMALIAN MIGRATIONS.**—This is the surest method of Tertiary intercontinental correlation and the principal one in use in the northern hemisphere. In South America it is of the greatest importance in correlating Pliocene and Pleistocene deposits, but of little or no use in the earlier Tertiary beds here under consideration because there is no clear evidence that any mammalian migration into or out of South America occurred while they were being laid down. The possible exceptions are the hystricomorph rodents, appearing in Deseadan times, and the ceboid primates, appearing in Santacrucian times (or possibly a little earlier), but these do not help, either, because their appearance cannot yet be definitely tied in with origin and temporal sequence in any other continent. The only important datum here is that the Riochican, with mammals surely Tertiary in type, can hardly be older than Paleocene or (even at the top) younger than early Eocene, a rather vague conclusion but one of considerable importance.

**MARINE CORRELATION.**—The marine beds, unlike those of terrestrial origin, include numerous forms of life that were not

confined to South America during the time here considered. They therefore afford an opportunity for correlation more exact and more firmly based than that of the terrestrial deposits. Their information is not entirely conclusive, as is shown by the fact that different students still do not agree as to the age of the rich Patagonian marine fauna, but it is the best available. This, then, is the real limiting basis of correlation for this sequence. Two marine deposits are included, the Salamanca and the Patagonia formations (which, of course, are, respectively, Salamancan and Patagonian in age). Salamancan time is older than Riochican, but probably grades into the latter because the deposits here suggest a transition rather than a break (but this is not altogether certain). A transition from Colhuehuapian to Patagonian is more certain, indeed the later Colhuehuapian deposits are supposed by most students to be contemporaneous with the first marine deposits of the Patagonian. Generally speaking the two stages are successive, but probably with no intervening hiatus.

The Salamancan has long been considered Cretaceous, and successive students have tended to consider it as younger and younger. For Ameghino it was Cenomanian and for most of his successors Senonian. Now Feruglio (1937) has emphasized the absence of indubitably and fully Cretaceous guide fossils and tentatively calls the Salamancan, Danian. On the basis of Feruglio's excellent study, and without essential contradiction of his own conclusions, there is considerable likelihood that the Salamancan is really earliest Tertiary (early Montian, or in the North American sequence, Puercan) or perhaps transitional Danian-Montian. I would so correlate it, and on this basis I believe that the overlying series cannot begin earlier than about the middle or possibly the early (but probably not basal) Paleocene and probably does not begin much later than that. The relations of the Salamanca formation in Patagonia may be closely analogous to those of the Cannonball in North America.

The Patagonian has always been con-



sidered Tertiary, which is unquestionably correct, but more exact correlation varies from early to middle Eocene (Ameghino) to about middle Miocene (Frenguelli). More than any other one factor, it is the age given the Patagonian that determines the general correlation groups discussed above. As far as I know, recent students vary in assignment from about middle Oligocene to about middle Miocene—a surprising divergence for so large and relatively well-known a marine fauna. The evidence and arguments are too lengthy for review here, involving as they do molluscs, crabs, echinoderms, corals, bryozoans, sharks, penguins, whales, and other fossils. Despite the differences of opinion, there seems to me to be a definite probability that the formation (at least the typical Patagonian as distinct from Superpatagonian) is of earliest Miocene or transitional Oligocene-Miocene age. I do not think that the most reliable, well-evaluated data can be reconciled with age assignments as early as middle Oligocene or as late as middle Miocene. On this basis the Colhuehuapian, very little earlier than Patagonian and perhaps partly contemporaneous with the oldest marine Patagonia, is probably late Oligocene, while the Santacrucian, only a little later than Patagonian, cannot be older than earliest Miocene or younger than middle Miocene. I tentatively place it as early (but not earliest) Miocene.

**INTERNAL EVOLUTIONARY ADVANCE.**—With limits thus set approximately by the marine beds, the problem becomes one of distributing the various provincial stages from Riochican to Colhuehuapian in the Paleocene to Oligocene, inclusive. There is no firm basis for doing this other than judgment of lapse of time by the evolutionary changes seen in the corresponding mammalian fossils. The Riochican includes certainly two and probably three distinctive faunas, and the fossils of the older Riochican are very poorly known. In itself, this stage suggests a lapse of time probably great enough to include both middle and late Paleocene. There is no significant gap (but there is a definite progressive step) from latest Riochican to

earliest Casamayoran mammals. The Casamayoran fits in best as about early Eocene. There is a marked gap between Casamayoran and Mustersian (as their characteristic faunas are now known). This gap may cover part or all of middle Eocene, possibly part of lower Eocene, and the Mustersian fits in as around the middle-late Eocene transition. Then, in the known faunas, comes another and still larger break which may represent part or all of late Eocene and part or (less probably) all of early Oligocene, and the best characterized Deseadan fauna would be near the early-middle Oligocene line. The next hiatus, also well marked but probably less in value, probably represents part of late, possibly (less probably) also part of middle Oligocene, and the Colhuehuapian falls into the latest Oligocene, as suggested by its relations to and the correlation of the Patagonian.

This arrangement is fully consonant with the actual evolution that occurred, as I now see it, and the more markedly different correlations that have been proposed do not well fit these considerations. Thus according to Kraglievich the early Casamayoran (to which he gives a different name) represents the Paleocene and the later Casamayoran the early Eocene, but there is exceedingly little advance from earliest to latest Casamayoran,<sup>1</sup> certainly far too little to permit such age assignments.

As an example of opposite tendency, Frenguelli (1934) puts Casamayoran to Deseadan all in the Oligocene and here, even allowing evolution then to have been relatively more rapid than in post-Oligocene South America, the changes seem to me much greater than occurred among autochthonous mammals in the Oligocene of North America or Europe. This amount of evolution is too great to be crowded into the Oligocene and accords far better with the span of the Eocene (which was longer than the Oligocene) plus part of the Oligocene.

<sup>1</sup> As a matter of fact none has ever been actually demonstrated, but new data now in hand suggest that there were slight changes, distinctly less than those from Gray Bull to Lost Cabin in the North American early Eocene.

These broad considerations, involving many detailed data not here listed, have

led to the tentative correlations given in the last column of the preceding table.

### THE GAIMAN REGION

My study of the Gaiman region (1935a and b) was severely criticized by Frenguelli (1935) and later generally supported by Bordas (1937, 1939) incidental to the description of a new fauna from there. The principal points in dispute are these:

(a) Local correlation of stratigraphic levels north and south of the Chubut River near Gaiman.

(b) Existence and character of an angular unconformity in this series.

(c) Presence of a terrestrial horizon in the strata designated as marine by Frenguelli in 1927.

(d) Broad correlation of the pre-Patagonian strata in this series.

(e) Presence of a lateral wedge of the formation mentioned in (c) north of the river.

(f) Presence of land mammals in the littoral marine Patagonian beds.

(g) Use of the stratigraphic names Trelew, Colhué-Huapi, and Musters.

As regards (a), (c), and (d), Frenguelli is now in substantial agreement with my conclusions. Bordas has also confirmed these conclusions and has strengthened them, notably in establishing that certain beds considered by Frenguelli in 1927 as Patagonian (Oligocene or Miocene) on one side of the river and Cretaceous on the other side are really Casamayor (Eocene) as I believed but could not rigidly prove in 1935.

At present, then, these points may be taken as settled, to the extent of agreement by all who have examined the evidence at first hand. The nomenclatural dispute (g) has been discussed on previous pages.

Regarding (b), Frenguelli in 1927 showed a strong angular unconformity in the strata on both sides of the Chubut River, involving an anticline in the older beds, shown as dipping away from the river on both sides, with the younger strata nearly horizontal above them. My conclusion (1935a) was that "it is to be expected that small angular unconformities exist, but the evidence is still lacking. If they are present, it seems almost certain that the angle involved is less than a degree." In

1935 Frenguelli reaffirmed the existence of an angular unconformity, but added that it is slight. He said that he could not otherwise interpret the details of two photographs (Frenguelli 1927, Figs. 40 and 41) and that it is not difficult to see angular unconformities on both sides of the valley. The photographs cited do not, in fact, show any angular unconformity but only isolated exposures of tilted and folded beds. I have already (1935a) confirmed that such tilted beds do exist but have shown that there are two possible alternative explanations for them, neither of which is consistent with Frenguelli's supposed angular unconformity or its supposed underlying anticline. Frenguelli did not discuss these possibilities in his later paper.

As regards the ease of observation of the supposed angular unconformity, I did not observe it, although I searched for it at the exact places indicated by Frenguelli. It is significant that Frenguelli claims throughout that there is only one unconformity of this nature but that in 1935 he shows it at an entirely different place from that indicated in 1927. It can hardly be easy to see if Frenguelli does not see it now where he did in 1927 and did not see it then where he does now. Bordas does not specifically discuss this question, but his general interpretation is contrary to the reality of Frenguelli's unconformity.

Of course any large erosional unconformity, such as certainly exists here, is likely also to be angular if the term be extended to dip differences of a fraction of a degree, but this has little tectonic and no economic significance. In parts of the meseta region there was folding after the Deseado and before the Patagonian depositional phases, as I can prove from observations made elsewhere, but the effect in this particular area was insignificant as far as present evidence shows. The question is local, but it has broad importance because just such questions of localization

are vital in the general interpretation of tectonic phases.

As Frenguelli notes, the only appreciable purely stratigraphic (non-structural) difference between my views and those that he reached after mine were published (but not before) is on point (e), that he denies the presence north of the river of the terrestrial horizon that he calls Colhuehuapiense and that I call Trelew or Trelewense. I noted that this level is there represented by mere lenticular remnants, absent in places and conformable with or even grading into the overlying marine beds. We agree that this formation is here wedging out, and the only difference is that I recognized its last traces on this side of the river and Frenguelli did not. Bordas confirms my observation.

Regarding (f), Frenguelli had reported the discovery of land mammals in marine beds. I pointed out that this is entirely possible, but that the available evidence was inconclusive because Frenguelli did not distinguish between truly marine (littoral) beds and others nearby of terrestrial deposition. In 1935 he stated that the fossils were really from the redefined marine beds, an observation that I do not question now that it is made precise. It is also confirmed by Bordas.

It might appear from Frenguelli's 1935 paper that he had previously corrected all the essential misinterpretations in his earlier work and that I wilfully omitted crediting him with these corrections. He has suggested (personal communication) that I write another note to clear up this matter. The point was not important enough for special publication, but the present paper gives occasion for brief mention.

Frenguelli's corrections after his 1927 paper and before mine of 1935 consisted of stating (1930) that he had found the "Colpodonense" with land mammals in the base of the Patagonian and that he had found Casamayor mammals west of Gaiman above his supposed angular unconformity. Both these observations had already been made many years before any of Frenguelli's papers, by Ameghino (1906) and by Roth (1908). These prior dis-

coveries were recorded along with Frenguelli's views in my historical résumé of the subject. I clearly dated his opinions and did not say or imply that he did not hold other views before or since the dates of his quoted publications. It did not seem necessary to me, in a rapid historic summary, to credit him with the discovery in 1929 of facts known more than twenty years earlier. As a matter of fact we still do not know what effect these repeated discoveries had on his opinions prior to publication of my paper, because in his publication between 1927 and 1935 he located them only with respect to an unconformity that he placed at very different levels in 1927 and, after reading my paper, in 1935.

Frenguelli is mistaken in saying (1935) that I believed his errors to have arisen chiefly from his belief in an angular unconformity and ignorance of the presence of Tertiary mammals in his complex "x," which he had called Patagonian marine but which includes also Casamayor and Trelew or Colhué-Huapí terrestrial beds. The stratigraphic sequence and correlation, which were the major points at issue, are not in the least influenced by the angular or non-angular nature of the unconformity, and I noted that Frenguelli and I and others before us had found Tertiary mammals in his series "x." To suppose that these were our chief points of difference overlooks all the real essentials of the matter.

Frenguelli's belief that I unjustly criticized his correlation of the beds now called Río Chico and his use of the name "Pehuenche" can only be a misunderstanding. In that paper (1935) I did not mention his use of the name "Pehuenche" and I had elsewhere credited him with being one of the few recent authors who avoided definite misuse of the name (the fact that in doing so he proposed equally invalid nomenclature is now beside the point). I simply mentioned his determination of these beds as Cretaceous as a fact that he had himself placed on record. I did not adversely criticize this determination, but showed that it was natural enough at the time and was disproved only by later



study. As a matter of proportion, readers of Dr. Frenguelli's polemic reply may not realize that my paper was not devoted to his work and was not a critical review. It was a record of my independent observations in the field and my interpretation of them. As is proper and necessary, I briefly summarized previous opinions, including those of Frenguelli among various others.

Dr. Frenguelli, subsequent to the appearance of my paper on the Gaiman region, emphasizes the essential agreement

of his opinions and mine and suggests that I should have confined my criticism to matters of detail. It is not as clear in Frenguelli's paper as I am sure he meant it to be that his present agreement with me is *ex post facto*, following his reading of my paper (1935a). When that paper was written all his prior explicit, published statements differed very materially and not merely in detail from the views that I then reached on the basis of my own observations and with which he now agrees.

### REFERENCES

- AMEGHINO, F.  
1906. "Les formations sédimentaires du crétacé supérieur et du tertiaire de Patagonie avec un parallèle entre leurs faunes mammalogiques et celles de l'ancien continent." *An. Mus. Nac. Buenos Aires*, XV, pp. 1-568.
- ASHLEY, G. H., AND OTHERS  
1933. "Classification and nomenclature of rock units." *Bull. Geol. Soc. Amer.*, XLIV, pp. 423-459.
- BORDAS, A. F.  
1937. "El afloramiento de Casamayor en el valle del Chubut." *Gaea, An. Soc. Arg. Est. Geog.*, V, pp. 215-220.  
1939. "Diagnosis sobre algunos mamíferos de las capas con *Colpodon* del valle del Río Chubut (Republica Argentina)." *Physis*, XIV, pp. 413-433.
- CASTELLANOS, A.  
1937. "Ameghino y la antigüedad del hombre sudamericano." *Assoc. Cult. Conf. Rosario (Argentina)*, 1936 Ciclo de caracter general, Pub. No. 2, pp. 47-192.
- FERUGLIO, E.  
1937. "Palaeontographica patagonica." *Mem. Ist. Geol. R. Univ. Padova*, XI.
- FOSSA-MANCINI, E., FERUGLIO, E., AND DE CAMPANA, J. C. JUSSEN  
1938. "Una reunión de geólogos de Y. P. F. y el problema de la terminología estratigráfica." *Bol. Inf. Petroleras Y. P. F. (Buenos Aires)*, XV, No. 171, pp. 31-95 (or reprint paged 1-67). (The part most directly pertinent to the present subject, pp. 82-95, or 54-67 of the reprint, is signed by Feruglio alone.)
- FRENGUELLI, J.  
1927. "El Entrerriense de Golfo Nuevo en el Chubut." *Bol. Acad. Nac. Ci. Córdoba (Argentina)*, XXIX, pp. 191-270.  
1930. "Nomenclatura estratigráfica patagónica." *An. Soc. Ci. Santa Fé (Argentina)*, III, (reprint pp. 1-117).  
1934. "Apuntes de geología patagónica." *Bol. Inf. Petroleras, Y. P. F. (Buenos Aires)*, X, No. 112, (reprint pp. 1-54).  
1935. "El perfil de Gaiman (Chubut)." *Notas Mus. La Plata, I, Geol.*, No. 1, pp. 177-192.
- KRAGLIEVICH, L.  
1930. "La formación Friaseana del Río Frías, Río Fénix, Laguna Blanca, etc. y su fauna de mamíferos." *Physis*, X, pp. 127-161.
- ROTH, S.  
1908. "Beitrag zur Gliederung der Sedimentablagerungen in Patagonien und der Pampasregion." *Neues Jahrb. Min., Geol., Pal., Beil. Bd.*, XXVI, pp. 9-2 150.
- SIMPSON, G. G.  
1933. "Stratigraphic nomenclature of the early Tertiary or Central Patagonia." *Amer. Mus. Novitates*, No. 644.  
1935a. "Early and middle Tertiary geology of the Gaiman region, Chubut, Argentina." *Amer. Mus. Novitates*, No. 775.  
1935b. "Occurrence and relationships of the Río Chico fauna of Patagonia." *Amer. Mus. Novitates*, No. 818.  
1940. "Review of the mammal-bearing Tertiary of South America." *Proc. Amer. Phil. Soc.*, LXXXIII, pp. 649-709. [Written after and, in part, based on the present paper.]

